

Flex Based Fuel Cell

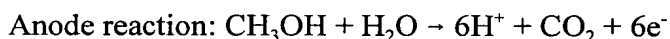
Technical Field

The technical field is fuel cells, with or without proton exchange membranes.

Background

A fuel cell is an electrochemical apparatus wherein chemical energy generated from a combination of a fuel with an oxidant is converted to electric energy in the presence of a catalyst. The fuel is fed to an anode, which has a negative polarity, and the oxidant is fed to a cathode, which, conversely, has a positive polarity. The two electrodes are connected within the fuel cell by an electrolyte to transmit protons from the anode to the cathode. The electrolyte can be an acidic or an alkaline solution, or a solid polymer ion-exchange membrane characterized by a high ionic conductivity. The solid polymer electrolyte is often referred to as a proton exchange membrane (PEM).

In fuel cells employing liquid fuel, such as methanol, and an oxygen-containing oxidant, such as air or pure oxygen, the methanol is oxidized at an anode catalyst layer to produce protons and carbon dioxide. The protons migrate through the PEM from the anode to the cathode. At a cathode catalyst layer, oxygen reacts with the protons to form water. The anode and cathode reactions in this type of direct methanol fuel cell are shown in the following equations:



The essential requirements of typical fuel cells (see, e.g., Figure 1) include: first, the fuel cell requires efficient delivery of fuel and air to the electrode, which typically requires complicated microchannels and plumbing structures. A second requirement is that the fuel cell should provide easy access to the catalyst and a large surface area for reaction. This second requirement can be satisfied by using an electrode made of an electrically conductive porous substrate that renders the electrode permeable to fluid reactants and products in the fuel cell. To increase the surface area for reaction, the catalyst can also be filled into or deposited onto a porous substrate. However, these modifications result in a fragile porous electrode that may need additional mechanical support, such as by use of a fiber matrix.

1 Alternatively, the electrode can be made of an etched porous Vycor glass substrate
2 or an etched-nuclear-particle-track membrane substrate to improve its toughness
3 and strength. A third requirement is close contact between the electrode, the
4 catalyst, and the PEM. The interface between the electrode and PEM is a
5 discontinuity area as concerns the electric current transmission wherein the charge
6 carriers are the electrons, on one side, and the protons on the other side. A solution
7 to this problem has been attempted by hot pressing of the electrodes onto the PEM
8 (U.S. Patent No. 3,134,697). Another solution suggests the intimate contact of the
9 catalytic particles with a protonic conductor before interfacing the electrode with
10 the electrolyte (U.S. Patent No. 4,876,115). Other solutions are described in U.S.
11 Patent Nos. 5,482,792 and 6,022,634. A fourth requirement is that the fuel cell
12 should provide for humidity control of the electrode. The PEM requires water to
13 be effective in conducting proton. However, since it operates at a higher
14 temperature than its surroundings, the PEM tends to dehydrate during operation.
15 The typical method of re-hydrating the PEM is to capture water in the exhaust
16 stream and circulate it back to the PEM.

17 **Summary**

18 A flex based fuel cell comprises two flex circuits assembled face-to-face
19 with PEM layers in between. Each flex circuit includes layers of a flex substrate, a
20 patterned conductive material, a porous material sheet with a catalyst coating, and a
21 PEM.

22 The catalyst coating on the porous material provides a large surface area for
23 chemical reactions to proceed and small gaps in the porous material deliver liquid
24 fuel to the catalyst through capillary force. The support of a soggy PEM on a
25 porous electrode may be achieved by assembling two flex substrates face-to-face
26 with the PEM constrained between the two flex substrates.

27 The flex substrates can bend in such a fashion to form a closed structure for
28 confining the fuel. The delivery of the fuel can then be achieved by capillary force
29 of a porous material sheet with the fuel distributed uniformly to all active surfaces,
30 as long as a portion of the porous material sheet is in contact with the liquid fuel.
31 Microchannels and plumbing are not required.

1 The flex based fuel cell can confine water between the two flex substrates
2 to provide moisture for the PEM. Since deionized water can easily conduct
3 protons but not electrons, a fuel cell can be constructed without the PEM. Two
4 flex substrates without the PEM layer can be bonded together face-to-face with an
5 adhesive layer in between as ridges.

6 The flex substrate, such as one using Kapton, provides additional
7 advantages. The electrodes can be patterned directly on the flex substrate, thereby
8 connecting different fuel cell panels in either serial or parallel manner.

9 In an embodiment, the flex substrates are formed into a cylinder. The
10 interior side of the cylinder would be the fuel side, and the exterior of the cylinder
11 would be the oxygen side. The fuel cell can be sealed at the bottom of the cylinder
12 to provide a container for the liquid fuel. The liquid fuel, such as methanol, is
13 delivered by the porous metal to the active catalytic surface of the interior side.
14 Protons generated in the cylinder interior then diffuse through the PEM and reach
15 the catalytic surface on the exterior side of the cylinder, where the protons combine
16 with oxygen. The exterior side of the fuel cell is open to the atmosphere, which
17 serves to supply the oxygen to the cylinder and carry away the reactant water vapor.

18 The flex substrates can be manufactured by the following steps:

19 (1) Patterning the flex substrate, such as Kapton (Dupont) or Upilex (Ube),
20 with a thin film of conductive material. The patterning of the thin film
21 provides the flexibility to define the size of fuel cell panels, as well as to
22 configure the fuel cell for any particular current density or voltage output by
23 routing the thin film patterning appropriately.

24 (2) Attaching a porous material sheet to the patterned thin film on the flex.

25 In an embodiment, the porous material may be a porous metal.

26 Alternatively, other porous materials may be used. For example, an
27 organo-metallic solgel material may be attached to the patterned thin film.

28 The attachment step can be accomplished by either attaching a
29 commercially available porous metal sheet on the flex, or sintering a thick
30 layer of porous metal on the flex. A thick porous metal layer can also be
31 manufactured by applying a paste of low temperature metal powder, such as

1 zinc nano particles (Aldrich catalog # 48,393-1) mixed in glycol, and
2 baking the resulting assembly in an oven to dry out the glycol and partially
3 melt the metal particles. The metal powder paste can be screen printed on
4 the flex substrate so that the location and shape of the sintered porous metal
5 can conform to the thin film electrode previously patterned on the flex
6 substrate. As an alternative to the zinc powdered metal, silver powder may
7 be used.

8 (3) Depositing a catalytic coating on the porous material sheet. Several
9 catalytic materials, such as Pt-Ru and Pt-Ru-Os, are effective in converting
10 methanol to proton without poisoning platinum in the flex substrate.

11 (4) Ablating backside openings to allow access to the catalytic surfaces.
12 The flex substrate is ablated with a laser from the backside to create
13 openings so that fuel on the cathode side and oxygen on the anode side can
14 reach the active catalytic surfaces through the openings and the porous
15 metal layer.

16 (5) For those flex substrates with a PEM, the surface of the catalytic coating
17 may then be coated with a thin layer of PEM by dipping the structure into a
18 5% Nafion solution. A thin layer of PEM on top of the catalyst surface
19 helps to capture protons. The thickness of the PEM may be controlled so
20 that the liquid fuel can readily diffuse through the thin layer.

21 Two flex substrates can then be assembled face-to-face with the PEM in
22 between to form a flex based fuel cell. For fuel cells without the PEM, two flex
23 circuits manufactured with only the first four steps (without the PEM coating step)
24 are assembled face-to-face with the catalytic coating layer in between.

Description of the Drawings

The detailed description will refer to the following drawings, in which like numerals refer to like elements, and in which:

Figure 1 illustrates a prior art fuel cell assembly;

Figure 2 shows a cross section of a flex based fuel cell having two flex circuits assembled face-to-face with a proton exchange membrane PEM in between;

Figures 3A and 3B show a top sectional view and a plan view of the fuel cell assembly;

Figure 4 shows a flex based cylindrical fuel cell assembly;

Figures 5A - 5E show a process for manufacturing the flex based fuel cell; and

Figure 6 shows an alternative flex based fuel cell.

Detailed Description

Figure 2 is a simplified cross-section view showing an exemplary flex based fuel cell 100. The fuel cell 100 includes a right flex circuit A and a left flex circuit B. This naming convention is purely arbitrary and is used to add greater clarity to the description of the flex based fuel cell 100. Two flex substrates 101 and 102 are assembled face-to-face together with a PEM 103 in between. On either side of the PEM 103 are porous material and catalyst layers 104. Adjacent to the PEM 103 is a palladium (Pd) layer 105 that prevents cross-over of the methanol fuel. Adjacent to the porous material and catalyst layers 104 are anode and cathode electrodes (conductors) 106 and 107. A dry film adhesive 108 serves to separate portions of the fuel cell 100. Recycled water 109 flows through the fuel cell 100, as shown. A liquid fuel 110, such as methanol, for example, is provided on the anode side of the fuel cell 100. Air and water vapor 111 flow past the cathode electrode 107. The methanol fuel 110 has direct contact with the porous material layers 104 through openings 112 in flex substrates 101, 102. The methanol fuel 110 is delivered by the porous material layers 104 to an active catalytic surface 105 where CH_3OH reacts with H_2O (methanol) to form CO_2 and protons. The protons then diffuse through the PEM layer 103 and reach a catalytic layer 107, where the

1 protons combine with oxygen to form H₂O. The left flex circuit B of the fuel cell
2 100 is open to the atmosphere, which serves to supply the oxygen to the fuel cell,
3 and carry away the reactant water vapor 111.

4 In an embodiment, the porous material layers 104 are formed of a porous
5 metal material such as zinc or silver powder. The porous metal layers 104 deliver
6 the liquid fuel (methanol) 110 by means of capillary action. Capillary action
7 depends on the fact that a liquid near a solid wall will undergo curvature of the
8 liquid surface. The amount of curvature depends on the difference between surface
9 tension of the solid-vapor film (S_{LV}) and surface tension of the solid-liquid film
10 (S_{LV}). Depending on the liquid and the solid, the curvature can be positive,
11 negative or zero. In the case of a liquid such as methanol that wets the pores in the
12 porous metal layer 104, the methanol will rise in the pores until an equilibrium
13 height y is reached:

$$y = \frac{2S_{LV} \cos \theta}{\rho g r}$$

15 where:

16 r = radius of pores

17 θ = contact angle of the liquid methanol the pores.

18 Thus, by careful design, the liquid fuel (methanol) 110 can be made to
19 supply all portions of the fuel cell 100 without elaborate pumps and plumbing.
20 Note that pores in the porous metal layer 104 may be oriented in the local plane, or
21 substantially in the local plane defined by the flexible substrates 101, 102. The
22 pores may be further oriented such that liquid fuel will be transported in a specified
23 direction (e.g. vertically) within the porous metal layer 104 so that liquid fuel
24 reaches all, or substantially all, of the fuel side flex circuit A (see Figure 2).

25 As shown in Figures 3A and 3B, two or more fuel cells 100 can be bonded
26 together in such a way that there is an enclosed space 120 between two fuel cells
27 100. The enclosed space 120 is filled with water or a water containing solution to
28 provide moisture for the PEMs, which require water to be effective in conducting
29 protons.

1 As shown in Figure 4, a flex fuel cell assembly 130 can be shaped into the
2 form of a cylinder. An interior 131 of the cylinder would be the fuel side, and an
3 exterior 132 of the cylinder would be the oxygen side. The fuel cell can be sealed
4 at a top 133 and a bottom 134 of the cylinder interior 131 to provide a container for
5 the liquid fuel. Alternatively, the cylinder top may be left unsealed. In an
6 additional embodiment, liquid fuel may be supplied to the exterior 132 of the flex
7 fuel assembly 130.

8 In addition to the non-planar cylindrical shape shown in Figure 4, the flex
9 fuel cell assembly 130 may be shaped into other non-planar and substantially non-
10 planar shapes, including a polygon of N sides, a star having M points, where M
11 may be the integer 5 or larger, and an oval, for example. The flex fuel cell
12 assembly 130 may also be formed in a shape of a cross or other non-planar or
13 substantially non-planar form. These complex shapes have the advantage of
14 increasing the surface area for fuel cell reactions and power production.

15 Because the flex fuel assembly 130 can be molded to a variety of shapes,
16 the flex fuel assembly 130 is ideal for power applications that are constrained in
17 size and shape. Thus, a fuel cell system using the flex fuel assembly 130 can be
18 shaped to fit virtually any container or enclosure, allowing the fuel cell system to
19 be used in a wide variety of applications where prior art fuel cell systems would
20 not be useable.

21 Wrapping a flex substrate into the cylindrical shape as shown in Figure 4
22 has the added advantage of enhancing the adhesive effect between the Nafion and
23 the flex substrates. The enhanced adhesive effect occurs primarily because of the
24 compressive forces acting on the Nafion by the cylindrical flex substrates.

25 As noted above, the flex-based fuel cell 100 shown in Figure 2, as well as
26 other embodiments, such as the cylindrical fuel cell 130 shown in Figure 4, may
27 use capillary action to draw liquid fuel, such as methanol, to all active regions of
28 the fuel cell. The rate of capillary action may be controlled by adjusting the pore
29 size (diameter) of pores in the porous metal and catalytic layers 104. Using
30 capillary action to move the liquid fuel through the fuel cell 100 allows the fuel cell

1 100 to operate without expensive and bulky pumps, valves and piping, thereby
2 making the fuel cell lighter and more desirable for portable power applications.

3 Figures 5A-5E depict processing steps for manufacturing the flex circuits.
4 As shown in Figure 5A, which includes a plan view and a side view, the first step
5 is to metallize a flex substrate 150, using a material such as Kapton or Upilex, to
6 form a thin film electrode 151 in a predetermined pattern. The patterning of the
7 thin film electrode 151 defines the size of the cell panels, and configures the fuel
8 cell for any particular current density or voltage output.

9 The next step, as shown in Figure 5B (which includes plan and side views),
10 is to attach a porous metal layer 152 to the patterned thin film electrode 151 on the
11 flex substrate 150. The porous metal layer 152 can be a commercially available
12 porous metal sheet. Alternatively, a thick porous metal layer can be sintered on the
13 flex. Referring to Figure 5B, a paste of low temperature metal powder such as zinc
14 nano particles mixed in glycol, is applied on top of the thin film electrodes 151.
15 Alternatively, silver powder may be used. The flex substrate 150 is then baked in
16 an oven to dry out the glycol and partially melt the metal particles to form a thick
17 layer of porous metal. The metal powder paste also may be screen printed on the
18 flex substrate 150 so that the location and shape of the sintered porous metal can
19 conform to the thin film electrode 151 previously patterned on the flex substrate
20 150.

21 The next step, as shown in Figure 5C (including plan and side views), is to
22 deposit a layer 153 of catalytic coating on the porous metal layer 152. Referring to
23 the composition of catalytic coating for fuel cells using methanol, catalytic
24 materials such as Pt-Ru and Pt-Ru-Os, are found to be effective in converting
25 methanol to protons without poisoning other fuel cell constituents.

26 The next step, as shown in Figure 5D (again showing plan and side views),
27 is to laser ablate backside openings 154 on the flex substrate 150 and the thin film
28 electrodes 151, so that the fuel or oxygen can reach the active catalytic layer 153
29 through openings in the flex substrate 150 and the porous metal layer 152.

30 The final step, as shown in Figure 5E (plan and side views), is to cover the
31 surface of the catalytic layer 153 with a thin layer of PEM 155. In a preferred

1 embodiment, the flex structure is dipped into a 5% Nafion solution. A thickness
2 of the PEM 155 should also be controlled so that the liquid fuel can diffuse through
3 this thin layer.

4 Figure 6 illustrates an alternative embodiment of a flex circuit for use in a
5 flex based fuel cell. The flex based fuel cell includes a plurality of flex circuits. A
6 flex circuit 200 includes a right, or fuel-side flex circuit C and a left, or air-side
7 flex circuit D. This naming convention is purely arbitrary and is used to add
8 greater clarity to the description of the flex circuit 200.

9 The flex circuit 200 includes flex substrates 201 and 202, each having
10 openings 212. In immediate contact with the flex substrates 201 and 202 are
11 conductors 206 and 207. Adjacent the conductors 206, 207 are porous metal and
12 catalyst layers 204. In an embodiment, the catalyst may be Pt-Ru or Pt-Ru-Os.
13 The porous metal may be chosen so that the pores in the porous metal provide a
14 capillary action that draws fuel into the flex circuit 200. An adhesive 208 may be
15 used to seal the space between the porous metal and catalyst layers 204.

16 A liquid fuel 210, such as methanol, is supplied at the right side C of the
17 flex circuit 200. Air and water 211 are removed at the left side D of the flex circuit
18 200.

19 In a departure from other fuel cell designs, the flex circuit 200 does not use
20 a PEM. Instead, a thin layer 209 of dionized water is maintained between the
21 porous metal and catalyst layers 204. By maintaining a spacing between the porous
22 metal and catalyst layers 204, the flex circuit 200 is able to generate protons from
23 the liquid fuel 210 and the protons are combined with oxygen to form water. That
24 is, the dionized water conducts protons but does not conduct electrons. Thus, by
25 eliminating the PEM, the flex circuit 200 shown in Figure 6 is less costly to build.

26 Although preferred embodiments and their advantages have been described
27 in detail, various changes, substitutions and alterations can be made herein without
28 departing from the spirit and scope of the flex based fuel cell as defined by the
29 appended claims and their equivalents.